METHOD OF USING INTRINSICALLY CONDUCTIVE POLYMERS WITH INHERENT LUBRICATING PROPERTIES, AND A COMPOSITION HAVING AN INTRINSICALLY CONDUCTIVE POLYMER, FOR PROTECTING METAL SURFACES FROM GALLING AND CORROSION

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This invention relates to corrosion-protection and lubrication of metal surfaces. In particular, the invention relates to a method of protecting a metal surface, such as the surface of threaded joints in oil tubings or casings, by applying a dry film including a binding intrinsically conductive polymer to the surface. The invention also relates to a composition for protecting a metal surface from galling and corrosion.

Description of the Related Art and Problem to Be Solved

A. Intrinsically Conductive Polymers and Corrosion Protection

[0002] Intrinsically conductive polymers used as corrosion protection compounds are known in the art. One example of an intrinsically conductive polymer is polyaniline, which has been known to modify the electrochemical and corrosion behavior of stainless steels. For example, DeBerry has determined that stainless steel electrodes coated with thin films of polyaniline remain passive for long periods of time in acid solutions, even though normally they would be active and highly susceptible to corrosion in such environments (*J. Electrochem. Soc.: Electrochemical Science and Technology* 132 (5) (1985) 1022-1026). According to Gasparac et al., who have examined the mechanism of corrosion inhibition conferred by polyaniline on steel placed in a highly corrosive sulfuric acid solution, passivation is achieved because the polyaniline holds the potential of

stainless steel electrodes in a passive region, preventing corrosion (*J. Electrochem. Soc.* 148 (4) (2001) B138-B145).

[0003] Polyaniline can be an electrical conductor depending on its state of oxidation or doping. The corrosion protection mechanism involves both the conductive and the non-conductive states of polyaniline.

[0004] Wessling et al. (*Synth. Met.* 85 (1997) 1313-1318) have proposed a corrosion protection mechanism including the following steps: 1) Polyaniline in its conductive state (i.e., emeraldine base) depolarizes ferrous metal by accepting electrons, forming non-conductive polyaniline (leucoemeraldine). 2) Atmospheric oxygen regenerates the polyaniline to its conductive state (emeraldine).

[0005] Further, Gasparac et al. (*J. Electrochem. Soc.* 148 (4) (2001) B138-B145) have confirmed the proposed mechanism using polyaniline on stainless steel in the presence of oxygen.

[0006] Lu et al. have disclosed corrosion protection of mild steel by coatings containing polyaniline (*Synth. Met.* 71 (1995) 2163-2166), while Camalet et al. have disclosed the electrodeposition of protective polyaniline films on mild steel (*J. Electroanalytical Chem.* 416 (1996) 179-182). Rajagopalan et al. have disclosed two-intrinsically conductive-polymer, polyaniline-polypyrrole composite coatings formed on low carbon steel using an aqueous electrochemical process, which have anti-corrosive properties (*Surface Engineering* 18 (1) (2002) 53-63). And Kraljic et al. have disclosed inhibition of steel corrosion by polyaniline coatings electrosynthesized on steel samples using sulfuric and phosphoric acids as supporting electrolytes (*Corrosion Science* 45 (2003) 181-198).

[0007] Previously, intrinsically conductive polymers have been provided on metal surfaces through direct application by electropolymerization onto a metal surface, as well as by deposition of solutions of previously polymerized monomers.

[0008] In methods involving the deposition of a solution of previously polymerized monomers, the polymer has been included in a binding, such as a polyaliphatic-diamine resin (U.S. Patent No. 6,500,544 to Tiitu et al.), or an acrylate (European Patent Application No. 1 258 513 A2, Rohm and Haas Company).

[0009] Intrinsically conductive polymers have also been used as general binding agents and combined in composites with corrosion protection agents, such as 2,5-dimercapto-1,3,4 thiadiazole or trithiocyanuric acid (U.S. Patent Publication 2002/0197468 A1, Sinko).

[0010] The term "inherently conductive" or "intrinsically conductive" is sometimes used (for example, in U.S. Patent No. 5,567,355 to Wessling et al.) to describe conjugated materials (such as polyaniline) that do not require the addition of conductive materials (such as carbon or metal particles), but may or may not require doping (oxidation and/or protonation), in order to be conductive. Inherently conductive or intrinsically conductive polymers can thus be distinguished from "common" polymers (such as poly[methyl methacrylate]), which require a conductive material (such as graphite) dispersed therein to give the polymer conductivity.

[0011] Unlike non-conductive polymers such as titanates, silicones, epoxies, polyurethanes, and the like, the conductive properties of polyaniline account for both the anticorrosion mechanism and the possibility of an industrial application by electrodeposition or electrophoresis in a single step at high speed, without the use of

solvent, thus reducing slow drying steps. Polyaniline can also be sprayed or brush-painted on metal surfaces, like other polymers.

B. Lubricants and Galling Protection

[0012] Galling is a form of surface damage arising between sliding solids, distinguished by macroscopic, usually localized, roughening and creation of protrusions above the original surface. It often includes plastic flow or material transfer, or both. (ASTM definition.) A number of surface treatments are known for protection from galling of metal surfaces, such as the threaded connections of oil pipe joints.

[0013] For instance, molybdenum disulfide, colloidal graphite, and other compounds that present similar lamellar structures in the solid phase are commonly used as lubricants of metal surfaces. Such solid lubricants have been included in dry films with ketonic resins (U.S. Patent No. 4,692,988 to Shulver), epoxy resins (Chinese Patent No. 1218100 to Lanzhou Chem. Phys. Institute), and specially fluorinated poly[alkylidenes] (U.S. Patent No. 5,407,590 to Salvia) or polyethers (U.S. Patent No. 4,692,988 to Shulver) as binders and applied onto metal surfaces by different methods. Since the resins will usually cure once applied onto a metal surface, compositions usually include a curing agent and may contain toughening agents in the case of rubber binders.

[0014] However, the art does not disclose a method of using intrinsically conductive polymers with inherent lubricating properties, and a dry film having an intrinsically conductive polymer, for protecting metal surfaces from galling and corrosion.

[0015] For example, U.S. Patent No. 4,414,247 to Hubecker proposes a method of surface treatment of threading that involves the use of a resin varnish with a dispersion of

particles of solid molybdenum disulfide lubricant. However, no corrosion protection is provided.

[0016] U.S. Patent No. 4,692,988 to Shulver proposes applying a dry lubricant such as molybdenum disulfide to a screw thread, and applying a liquid lubricant such as oil to the other screw thread, during the assembly of a connection. Therefore, the patent does not disclose a dry lubricating process. It also does not disclose the use of conductive polymer to lubricate or protect from corrosion.

[0017] PCT Publication WO 02/18522 A1 (Vallourec Mannesmann Oil & Gas France, and Condat S.A.), which relates to a threaded joint for oil well pipes, also teaches the use of oil in a lubricating substance applied to a threaded component, so it cannot be considered to disclose a dry lubricating process.

[0018] PCT Publication WO 01/16516 A1 (Sumitomo Metal Industries, Ltd.) discloses a rust-inhibiting coating including a layer of oil containing rust inhibitors. This coating is applied to a threaded joint, over a coating of dry lubricant, and must be removed in the oil field before assembling the connection, thus complicating operations.

[0019] U.S. Patent No. 6,027,145 to Tsuru et al., which relates to a threaded joint having high galling resistance, discloses a resin coating layer in which at least one powder selected from the group consisting of molybdenum disulfide and tungsten disulfide is dispersed and mixed. The resins are epoxy, furan, or polyamide, which are very different from the conductive polymers of this invention. The resin layer is formed on, and has a thickness larger than, a phosphate chemical formation coating layer. The patent does not teach the use of an intrinsically conductive polymer layer as an anti-galling and anti-corrosive coating, alone or in combination with molybdenum disulfide.

[0020] U.S. Patent Publication 2002/0166770 A1 (Kimpel et al.) discloses a process for producing a multi-layer coating. A primer layer, which is electrically conductive in the at least partially-cured state, is applied by electrodeposition from an electrodeposition coating agent (I) to an electrically conductive object. The primer layer is at least partially cured exclusively by the action of near infra-red radiation, and an additional coating layer is applied by electrodeposition from an electrodeposition coating agent (II). The additional coating layer, as well as completely uncured or incompletely cured area parts of the primer layer, are then cured. The electrodeposition coating agent (I) contains one or more electrically conductive constituents, which confer a volume resistivity on the electrodeposition coating layer and may include, among other possibilities, graphite, molybdenum disulfide, or intrinsically conductive polymers such as polyaniline. This publication does not teach that the multi-layer coating has lubricant properties.

[0021] U.S. Patent Publication 2002/0114940 (Clemens et al.) discloses a coating system that includes a basecoat of a thermosetting asphalt extended, chemically cross-linked urethane/epoxy hybrid basecoat resting on a substrate, and a thermoplastic powder coating topcoat overlying at least the base coat. Corrosion inhibitors, which include polyaniline, and fillers and lubricants, which include molybdenum disulfide, are optionally included in the coating system. According to this publication, polyaniline is used as a corrosion protection additive, not as a binding intrinsically conductive polymer.

[0022] Italian Patent Application RM 2002 A000512 (Tenaris Connections Ltd./AG) discloses a surface treatment including a first uniform layer of a dry corrosion inhibiting coating and a second uniform layer of a dry lubricant coating applied over the first layer. It also discloses a uniform layer of dry corrosion inhibiting coating that contains a dispersion of particles of solid lubricant. However, the application does not teach a

homogeneous layer of an intrinsically conductive, anti-corrosive polymer, which itself prevents galling and may be mixed with solid lubricant particles.

[0023] U.S. Patent No. 5,980,723 to Runge-Marchese et al. discloses an anodization process for forming a composite polymer-metal oxide film on a metallic substrate, such as aluminum. The process includes the steps of anodizing the metallic substrate, thereby forming an anodic film, and simultaneously depositing a polymer within the anodic film. The anodizing and depositing steps employ an electrolyte including an intrinsically conductive polymer, such as sulfonated polyaniline, and a protonic acid solution as an oxidizing agent. According to the patent, metal oxide formation is required. The composite polymer-metal oxide film can be formed on other metal substrates aside from aluminum, such as copper, steel, silicon, zinc, magnesium, or titanium. However, since anodization cannot be performed on iron (and iron-based alloys) or carbon steel surfaces, iron and carbon steel are not suitable metal substrates for the process of Runge-Marchese et al.

[0024] None of the above documents discloses a dry coating that is based on a dispersion of a solid lubricant in an inherently or intrinsically conductive polymer that is both an anticorrosive and a lubricant in itself.

[0025] Although polyaniline by itself is a lubricant that shows good anti-galling properties and also protects from corrosion, it acts synergistically with molybdenum disulfide in terms of anti-galling protection. Accordingly, in one embodiment according to our invention, described more fully later, polyaniline is combined with molybdenum disulfide in a surface composite.

SUMMARY OF THE INVENTION

[0026] It is an object of the invention to provide protection from galling to metal surfaces, particularly threaded joint surfaces in oil tubing and casing subjected to high pressure, high friction, and high torque conditions.

[0027] It is another object of the invention to provide both galling-protection and corrosion-protection to metal surfaces through a simple application of a single compound.

[0028] The invention makes use of intrinsically conductive polymers, previously described as a corrosion protection agent, as non-oily and non-liquid organic lubricants for metal surfaces.

[0029] In one aspect according to the invention, a method for protecting a metal surface from galling and corrosion is provided. The method includes a step of applying a dry film comprising a binding intrinsically conductive polymer to the metal surface. The intrinsically conductive polymer itself has lubricant properties and is capable of binding solid lubricants to the metal surface.

[0030] The invention provides, in another aspect, a composition for protecting a metal surface from galling and corrosion. The composition includes a binding intrinsically conductive polymer with lubricant properties, and a solid lubricant.

[0031] In an embodiment of the invention, a surface treatment comprises the deposition onto a metal surface of a dry film including polyaniline, the polyaniline having lubricating properties and acting as a binding agent for molybdenum disulfide. The dry film may contain high amounts of the molybdenum disulfide, for example, in a proportion of four times the polyaniline by mass. The surface treatment may include pretreatment of the metal surface through chemical deposition of a conversion coating

(that is, a coating that chemically changes the surface of a metallic part) such as, for example, manganese phosphate, zinc phosphate, oxalate, and the like; or chemical deposition of a copper layer onto high chromium alloy.

[0032] Surface protection is achieved by mechanical deposition onto the metal surface of mixtures of the molybdenum disulfide and the polyaniline dissolved in an adequate solvent. Suitable methods of mechanical deposition include painting with a brush or spraying by aerosol. Surface protection may also be achieved by electropolymerization onto the metal surface of the anilines/monomers in the presence of the molybdenum disulfide and other additives. Electrodeposition can be obtained by applying a suitable (electrode) potential to the metal surface immersed in an electrolytic aqueous solution containing aniline/monomer. Alternatively, the molybdenum disulfide can be entrapped in a polyaniline/polymer film by electrophoretic deposition of the lubricating mixture onto the metal surface.

[0033] Additives may be included in the dry film in order to enhance properties such as anti-corrosive properties, high stability of the polyaniline-molybdenum disulfide mixture, or improved adherence of the dry film. The properties of the dry film can also be modified by post-chemical treatment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] FIG. 1 is a cross-sectional view of the set-up of a ring-on-disk test.

[0035] FIG. 2 shows an enlarged cross-section of part of the set-up of FIG. 1.

[0036] FIG. 3 is a graph of a typical result of a ring-on-disk test

[0037] FIG. 4 is an SEM image of a sliding surface, showing severe galling after a ring-on-disk test.

[0038] FIG. 5 is an SEM image, taken after a ring-on-disk test, of the sliding surface of a phosphated disk treated with dry film (polyaniline + MoS_2).

[0039] FIG. 6 is an SEM image, taken after a ring-on-disk test, showing detail of the sliding surface of a phosphated disk treated with dry film (polyaniline + MoS_2).

DETAILED DESCRIPTION OF THE INVENTION

[0040] The present invention relates to composition, preparation, and application of a dry film to steel and other metal surfaces, such as the surface of a threaded joint in an oil pipe, in order to protect the metal against galling under high applied torque, as well as to confer resistance to corrosion.

[0041] The dry film of the invention comprises a solid lubricant selected from those commonly used for lubrication purposes, such as molybdenum disulfide, graphite, or mixtures thereof; and a binding intrinsically conductive polymer such as polyaniline, polyprrole, or copolymers or modifications of these polymers.

[0042] Polyaniline used in the dry film may be prepared according to various methods, such as those described by Ponzio et al. (*Polym. Int* 50 (2001) 1180-1185), Cao et al. (*Polymer* 30 (1989) 2305-2311), Stejskal et al. (*Synth. Met.* 105 (1999) 195-202), Sun et al. (*Synth. Met.* 84 (1997) 99-100), Mattoso et al. (*Synth. Met.* 68 (1994) 1-11), Singh et al. (*Polymer* 38 (1997) 4897-4902), U.S. Patent No. 5,519,111 to McDiarmid et al., and U.S. Patent No. 5,567,355 to Wessling et al. A survey of methods of synthesis of polyaniline and its properties is reported by Genies et al. in *Synth. Met.* 36 (1990) 139-

182, and a standardized test protocol for preparation of polyaniline is reported by Stejskal et al. in *Pure Appl. Chem.*74 (5) (2002) 857-867.

[0043] Modified polyaniline can also be used for preparation of the dry film. Modification may be carried out on the polymer, both in the ring (Yue et al., *J. Am Chem. Soc.* 113 (1991) 2665-2671) and in the nitrogen (Hwang et al. Synth. Met. 92 (1998) 39-46). Further, it is possible to polymerize a chemically-modified monomer or a mixture of monomers to obtain copolymers (see, for example, Mattoso et al., *Synth. Met.* 68 (1994) 1-11).

[0044] The presence of a solid lubricant is not necessary in the dry film. By itself, a conducting polymer, such as polyaniline, has lubricating or anti-galling properties as well as anti-corrosion properties. For instance, a simple polyaniline prepared and applied onto a metal surface in a manner according to the invention provides a lubricating coating that performs comparably or even better than many conventional oils. Further, the dry film does not pose the leakage problems associated with conventional oils. Nor does it contain heavy metals (such as lead), which oils often have, that are harmful to the environment.

[0045] Nevertheless, performance of the dry film used in the invention is improved when the film includes a high concentration of solid lubricant. As an example, addition of molybdenum disulfide in a 4:1 disulfide-to-polymer weight ratio improves the lubrication between two metal surfaces under pressure.

[0046] Preferably, the dry film has polyaniline in its emeraldine base form as the intrinsically conductive polymer, and molybdenum disulfide as the solid lubricant, in a 1:4 to 1:2 weight ratio. The best performance can be achieved by dissolving these components in fifty parts by weight of N-methylpyrrolidone (NMP) solvent. This liquid

composite is then sprayed over a cleaned metal surface to be treated. Once the metal surface is dry, another layer of liquid composite may be applied, and best results are obtained by applying about 5 to 20 twenty layers of the composite by repeating the process described. The typical thickness of the dry supported lubricant film is about 1 to about 2 micrometers per layer of applied liquid composite, depending on the concentration of intrinsically conductive polymer in the liquid composite.

[0047] According to the invention, the dry film does not require additives to help achieve protection against galling and corrosion. However, such additives, like dispersing agents for the solid lubricants or agents for stabilizing highly concentrated polymer solutions, are not excluded. Other agents may be a complementary inhibitor added to improve corrosion resistance, and a surfactant added to stabilize a suspension of the solid lubricant. In cases in which the dry film is provided by electrodeposition, possible additives may also include, for example, an agent for improving compatibility of a monomer and a solid lubricant in a particular solvent.

[0048] The dry film may be applied to metal surfaces by any physical method for deposition of a liquid composite, such as application by spray or by painting with a brush. The film may also be applied by electrophoresis, as well as electropolymerization of monomers (or mixtures of monomers) in the presence of a solid lubricant or mixtures of solid lubricants. Preferably, the liquid composite is applied by spray, which has an advantage of producing more homogeneous films and lends itself to use in field application and inclusion in a repair kit.

[0049] The dry film may be applied onto a bare metal surface such as iron, steel, or stainless steel. It can also be applied, for example, onto a copper layer or a manganese phosphate layer previously deposited onto a metal surface. When one of the surfaces

involved in a joint or in a friction couple ("pin and box" in the oil industry) is chemically pretreated by manganese phosphate, higher galling resistance has been observed. In the case in which the dry film is provided by electrodeposition, manganese phosphate and the conducting polymer layer may be co-deposited, or simultaneously grown.

[0050] In one preferred embodiment of the invention, the dry film is applied to the surface of a box (that is, the internal female threaded end of a connection) pre-treated with manganese phosphate. The corresponding pin (that is, the external male threaded end of a connection) is coated with polyaniline only, to provide additional corrosion protection to the pin-and-box couple.

[0051] The method and dry film of the invention are further illustrated in the following non-limiting examples.

[0052] Preparation of the liquid composite

[0053] Polyaniline (or polypyrrole) is first prepared by chemical polymerization of aniline (or pyrrole) with sodium persulfate as an oxidant in the presence of sulfuric or phosphoric acid.

[0054] When the polymerization reaction is complete, the polyaniline, which will be in its emeraldine oxidation form (protonated or salt form), is filtered. The green powder is then re-suspended in a stirred solution of ammonium hydroxide for a few hours, after which the solution is filtered again and the dark blue polymer (emeraldine base form) is dried until no water remains. High reaction yields, of over about 70%, are obtained.

[0055] If the polymer is not used immediately, care must be taken to keep it dry. Alternatively, it should be re-dried prior to preparation of its liquid solution for application to metal surfaces. Drying conditions are typically 3 hours at 60 °C or overnight in a vacuum oven at 40 °C.

[0056] Then, with intense stirring, dry polyaniline is slowly dissolved in NMP in a preferred range of about 2% to about 5% by weight. After addition of all of the polymer, the solution is left to stand for a few minutes, though no more than about 10 minutes in order to avoid formation of gels. Solutions prepared in the above manner remain stable for at least several weeks.

[0057] Solid lubricant may be added to the polymer solution with continuous stirring during the addition. Preferably, the mass of lubricant is adjusted so that it is in about a 1:4 ratio by weight in relation to the polymer, or about 2% to about 10 % by weight in relation to the solvent.

[0058] Anti-galling tests

[0059] The dry film was tested on 1% Cr steel surfaces in two experiments, in each of which a metal joint was subject to high friction conditions in order to test resistance to galling or delay in the appearance of galling.

[0060] FIGS. 1 and 2 depict schematics of a "ring-on-disk" test layout. Reference numeral 10 denotes an electric motor that applies rotation to a ring-shaped part (24 in FIG. 2) at a given speed. Reference numeral 20 corresponds to a ring-and-disk sample set being evaluated: the sample comprises the ring-shaped part 24 (FIG. 2) and a disc-shaped lower part (26 in FIG. 2). Reference numeral 30 denotes a torque load cell which is a device used to measure the resultant torque; reference numeral 40 denotes an axial load cell that measures applied axial load; and reference numeral 50 denotes a hydraulic piston employed to apply a controlled axial load (22 in FIG. 2 denotes an axis of load application).

[0061] In the first test, a ring-on-disk experiment, two plane surfaces were pressed together, and the upper surface was rotated under an applied pressure while the lower

surface remained fixed. The upper plane surface corresponds to the base of the ring-shaped part 24 that usually is not chemically treated, and the disc-shaped lower piece 26 is either pretreated by chemical deposition of manganese phosphate, glass peening, or sanding, or not pretreated at all.

[0062] The dried film can be applied by either physical deposition of the liquid composite or by electrochemical or electrophoretic techniques.

[0063] The ring-on-disk test consisted of monitoring torque over time. FIG. 3 is a graph of a typical test result. The applied pressure between ring and disk was increased up to 30 Kg/mm^2 and after that was kept constant. The torque value increased with the applied pressure. When the maximum pressure was reached, the torque value decreased and then remained almost constant, indicating a good lubrication process. When galling occurred, sharp fluctuations in torque value were observed. The time that elapses until the fluctuations begin is considered the characteristic time for the test.

[0064] FIG. 4 is a scanning electron micrograph (SEM) image of a sliding surface, not treated with the dry film, showing severe galling after a ring-on-disk test. FIGS. 5 and 6 are SEM images, taken after a ring-on-disk test, of the sliding surface of a phosphated disk treated with dry film (polyaniline + MoS_2). No galling was observed even after several hours of testing.

[0065] Table 1 shows that direct application over steel surfaces pretreated with manganese phosphate results in similar or better performance than applying commonly-used oily liquid lubricants.

[0066] Table 1. Ring-on-disk test results

Coating applied to phosphated steel disk	Average time before galling occurs
No lubricant applied	44 seconds
Metal-free industrial thread compound	480 seconds
Industrial thread compound containing copper and zinc	650 seconds
API thread compound containing copper, zinc, and lead	959 to 1469 seconds
Polyaniline + MoS_2 composite (1:2 and 1:4 weight ratios)	> 10,000 seconds

[0067] In the second experiment, couplings and pins of several diameters, of the type commercially known as "premium connection," were covered with the dry film and subjected to full scale "make-up and break-out" (M&B, thread-fastening and unfastening) operations conducted in accordance with ISO 13679 petroleum and natural gas industry procedures for the testing of casing and tubing connections. The dry film of the invention provided excellent lubrication and galling resistance to the connections even after the number of make-up and break-out cycles required by the ISO Standard had been exceeded. In Table 2, some typical full scale M&B test results for connections of different diameters and steel grades are presented.

[0068] Table 2. Full scale M&B test results

Diam. [in]	Steel Grade	Pin Treatment	Coupling Treatment	N° M&B	Galling	M&B Required
3 1/2	T95	Dry Film	$MnPO_4$	21	Yes	9
3 1/2	T95	Dry Film	$MnPO_4$	16	Yes	9
2 7/8	P110	Bare	$MnPO_4$ + Dry Film	28	NO	9
4 1/2	P110	Bare	$MnPO_4$ + Dry Film	19	Yes	9
4 1/2	P110	Bare	Dry Film	19	Yes	9
4 1/2	P110	Bare	Dry Film	18	Yes	9
7	L80	Bare	$MnPO_4$ + Dry Film	12	Yes	9
9 5/8	L80	Bare	$MnPO_4$ + Dry Film	20	NO	2
9 5/8	L80	Bare	$MnPO_4$ + Dry Film	20	NO	2

9 5/8	L80	Bare	$MnPO_4$ + Dry Film	10	NO	2
9 5/8	L80	Bare	$MnPO_4$ + Dry Film	10	NO	2
9 5/8	L80	Bare	$MnPO_4$ + Dry Film	10	NO	2
9 5/8	L80	Bare	$MnPO_4$ + Dry Film	10	NO	2

* Dry Film: polyaniline + MoS_2 composite
* N° M&B: number of make-up and break-out cycles.
 a) Where the entry in the Galling column is "Yes", the N° M&B number indicates the cycle during which galling took place.
 b) Where the entry in the Galling column is "NO", the N° M&B number indicates the number of cycles that elapsed, with no evidence of galling, before testing was stopped.
* Entries in the M&B Required column refer to the number of make-up and break-out cycles without galling required by the ISO 13679 standard.

[0069] Anti-corrosion test

[0070] Phosphated (manganese) 1% Cr steel samples and couplings were sprayed with the liquid composite, providing a dry composite layer with a thickness of between 2 and 20 microns. The samples were tested in a salt spray (fog) chamber following the ASTM B117 Standard Practice for Operating Salt Spray (Fog) Apparatus. Only after 600 hours of testing was corrosion observed on the samples, indicating good corrosion protection. Also, in testing of couplings exposed to a humid environment (riverside), no corrosion occurred even after three months of exposure.

[0071] While particular embodiments of the invention have been illustrated and described, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the invention. Furthermore, it is intended that the claims will cover all such modifications that are within the scope of the invention.

INDUSTRIAL APPLICABILITY

[0072] This invention provides a method for protecting a metal surface from galling and corrosion, and a composition for protecting a metal surface from galling and corrosion. We envision that the method and the composition can preferably be applied, for example, to any type of metal thread and any type of metal oil-pipe joint commonly used in the oil industry, in order to confer resistance to galling and corrosion in a simple and economical manner.